Modeling the Impact of Short-term Lead Exposure on Blood Lead Levels In Young Children

Authors: J. M. Donohue[1], W. Mendez[2], A. Shapiro[2] | Sponsor: E. Doyle[1]
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Abstract

The Environmental Protection Agency (EPA) Integrated Exposure Uptake Biokinetic (IEUBK) Model can be used to predict the risk of elevated blood lead levels in children exposed to environmental lead from a variety of sources. A major limitation of the model is its inability to predict the impact of short term or episodic increases in lead exposure on blood lead levels. The Office of Water (OW) contracted with ICF International Inc. to determine if the IEUBK model could be adapted so that it could predict changes in blood lead levels over timeframes consistent with a drinking water utility's quarterly monitoring program.

ICF updated the background levels of lead in ambient air, soils, household dust, drinking water and diet used by the model. They devised an interface for the model that facilitated data entry and batch operation. The model was calibrated to ensure that the background blood lead projections (with typical drinking water exposure concentrations) were consistent with the distributions of blood lead levels seen in the Centers for Disease Control and Prevention's National Health and Nutrition Examination Survey (NHANES) monitoring program. The calibrated model has been used to estimate impacts on blood lead distributions in children exposed to intermittent increases in lead from drinking water. The model was found to provide consistent results for exposure averaging timeframes as short as three months.

Monitoring under the EPA Lead and Copper Rule involves measuring lead concentrations in first-draw tap samples after the water has been stagnant for at least six hours, which does not represent average human consumption. However, the adapted IEUBK model allows the OW to examine the incremental impact of hypothetical increases in average daily lead exposures on blood lead levels in young children and thereby inform projections of potential health risks. [The views expressed in this abstract are those of the authors and do not necessarily reflect the views or policies of the U.S. EPA.]

Background

Lead and Copper Rule

Enacted in 1991; Implemented in 1992

Requires that no more than 10% of first draw tap water samples from residential sites selected based on risk for leaching of lead exceed the Action Levels for Lead and copper

- Lead Action Level = 15 µg/L
    - MCLG = 0 (protects against cancer, neurotoxicity and hypertension)
- Copper Action Level = 1.3 mg/L
    - MCLG = 1.3 mg/L (protects against acute nausea and indirectly liver damage in sensitive populations)

Exceeding the action level as defined by the Rule is intended to signal the need to corrosion control and public notification actions as defined by the act.

The action level was estimated to be protective against an increase in blood lead levels above 10 µg/dL given background levels at the time the rule was developed.

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Part 2

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Office of Water Short- Term Lead Exposure Model

The project was initiated as a result of failure of the Washington DC Water and Sewer Authority to adequately comply with the action level for Lead in 2003 as made public in 2004.

Project Goals

- Produce a model that will project the change in blood lead levels for young children when average exposures to lead from drinking water exceed the action levels for periods of 90 days or more.
  - Problem can exist for 90 days before detection
- Update Background Exposures

Model Exposure Inputs

Baseline exposure inputs, summarized in the adjacent chart, were derived from the IEUBK default values, modified by more recent data from the Children's Exposure Factors Handbook and other sources.

Baseline Exposure Inputs for the IEUBK Model

Age Range (months):	Birth-12	13-24	25-36	37-48	49-60	61-72	73-84
Absolute Dietary Absorption Fraction	0.5						
Absolute Absorption Fraction for Drinking Water	0.5						
Respiratory volume (m3/day)	4.0	5.1	6.0	6.8	7.8	8.8	10
Absolute Inhalation Absorption Fraction	0.32						
Water Consumption (L/day)	0.34	0.31	0.31	0.33	0.36	0.39	0.42
Total Soil + Dust Ingestion, gm/day	0.085	0.135	0.135	0.135	0.1	0.9	0.85
Soil-Dust Weighting Factor	0.45						
Lead Bioavailability from Soil and Dust	0.6						
Absorption Fraction, Soil and Dust	0.5						
Dietary (non-water) Lead Intake (µg/day)	3.16	2.6	2.87	2.74	2.61	2.64	2.99
Baseline Lead Concentration in Drinking Water (µg/L)	0.93						
Ambient Air Concentration, µg/m3	0.06						
Soil, House Dust Lead Concentration	Residential soil = 55 µg/gm, house dust = 162 µg/gm (NHEXAS) Residential Soil = 54 µg/gm, house dust = 192 µg/gm (HUD Survey)						

LEGEND Green: Unchanged from IEUBK Default | Red: Updated

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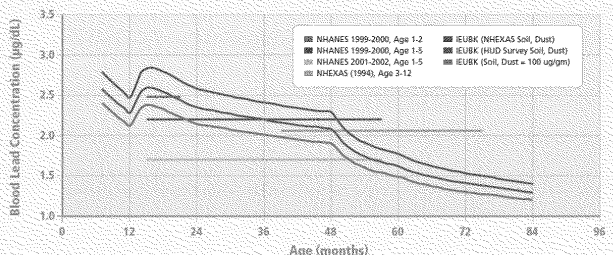
Modeling Results and Applications

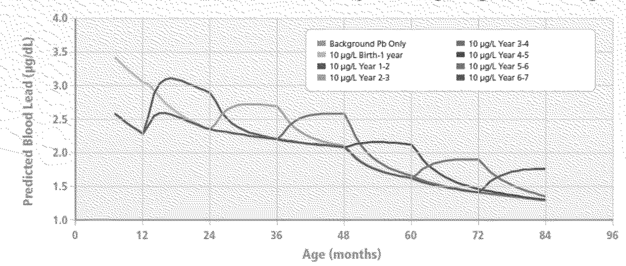
- **The Model is able to Accurately Reproduce Background Blood Lead Levels for Continuous Baseline Lead Exposures**

Comparison of IEUBK Predictions to Blood Lead Survey Results



Predicted Impacts on Children's Blood Lead Levels From a 10 µg/L Increase above a Drinking Water Baseline Value (0.93 µg/L)

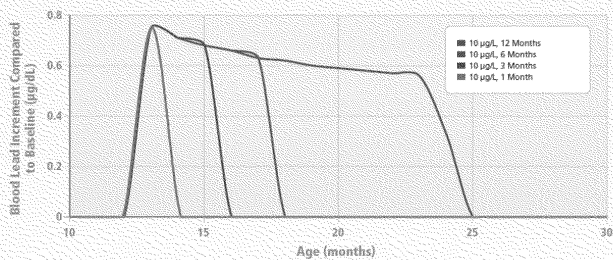
IEUBK Blood Lead Profiles for One Year Exposures Beginning at Different Ages



The thin colored lines in the graph represent the blood lead profiles for one-year exposures beginning at birth, age one year, etc., compared to the baseline blood lead profile as depicted by the thick blueline.

- **The Model Shows the Dynamic Response to Intermittent Increased Drinking Water Exposures (10 µg/L) lasting 1 month to 1 year beginning at age 12 months.**

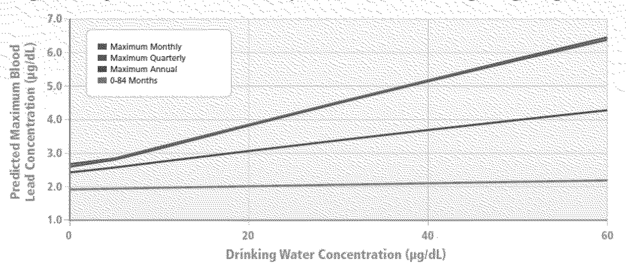
Maximum Predicted Blood GM Lead Increment for 10 µg/L Exposure from Drinking Water of One Month Duration or Greater Beginning at Age 12 Months



Peak predicted blood lead increments associated with each exposure are very nearly equal, showing the rapid response to sudden changes in drinking water lead exposures.

- **The Model Can Predict Changes in blood lead levels, averaged over different time periods, as a function of the magnitude of exposure increases (5-60 µg/L) for children of different ages.**

Maximum Predicted Geometric Mean Blood Lead Levels Are Linearly Related to Intermittent Drinking Water Exposure Concentrations (Exposure for Six Months Beginning at Age 12 Months)



The most important feature of the model results is the essential linearity of blood lead increments, averaged over widely varying time periods, in response to intermittent exposures in drinking water.

After six months exposure to drinking water lead > 40 µg/L, predicted maximum monthly and quarterly geometric mean blood levels will exceed the 5 µg/dL. Longer-term average blood lead predictions are less sensitive to intermittent exposures.

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Model's Projection of Effects on Blood Lead Levels and Intelligence Quotient (IQ)

- **Maximum average drinking water concentration (ug/L) associated with a maximum 1 µg/L increase in Geometric Mean (GM) Blood Lead Levels above background**

Average Drinking Water Lead Concentrations Increments Associated with Increased GM Blood Lead Levels

Age Group (Months)	Concentration in Drinking Water, µg/L		
	Monthly 1 µg/dL Increase	Quarterly 1 µg/dL Increase	Annual 1 µg/dL Increase
Birth-12	13	13	15
13-24	19	19	21
25-36	20	21	23
37-48	21	21	24
49-60	20	20	24
61-72	21	21	25
73-84	22	22	30

The linearity of the water lead-blood lead relationships for intermittent exposures allows the derivation of "slope factors" that can be used to predict children's blood lead increments over different averaging periods in response to short-term lead exposures from drinking water starting at different ages. This facilitates examination of the health implications of different short-term exposure scenarios.

- **Relationship of geometric mean blood lead levels to the blood lead levels of children at the high end of a population distribution**

95th and 99th Percentile Blood Lead (µg/dL) Estimates Associated with Geometric Mean Blood Lead Values, Assuming Different GSDs

Geometric Mean, µg/dL	GSD = 1.3		GSD = 1.6	
	95th perc.	99th perc.	95th perc.	99th perc.
1.0	1.5	1.8	2.2	3.0
1.5	2.3	2.8	3.2	4.5
2.0	3.1	3.7	4.3	6.0
2.5	3.8	4.6	5.4	7.5
3.0	4.6	5.5	6.5	9.0
3.5	5.4	6.4	7.6	10.4
4.0	6.2	7.4	8.7	11.9
4.5	6.9	8.3	9.7	13.4
5.0	7.7	9.2	10.8	14.9

LEGEND Yellow: Blood lead level exceeds 5 µ/dL | Green: Blood lead level exceeds 10 µ/dL

Applying the assumption of lognormality, it is possible to predict the proportion of children with blood lead levels above specific target levels given specific GM blood lead levels. Blood lead distributions were estimated using two different assumptions related to the geometric standard deviation (GSD) of the children's blood lead distribution.

- **IQ impacts associated with incremental increases in blood lead levels above background**

Estimated IQ Losses Associated with Increments In "Peak" Blood Lead Levels, Based on Lanphear (2005) Model

Blood Lead Increment, µg/dL	Baseline Blood Lead, µg/dL			
	1.0	1.5	2	2.5
0.2	-0.5	-0.4	-0.3	-0.2
0.4	-1.0	-0.7	-0.5	-0.4
0.6	-1.3	-1.0	-0.7	-0.6
0.8	-1.7	-1.2	-1.0	-0.8
1	-2.0	-1.5	-1.2	-1.0
1.2	-2.2	-1.7	-1.3	-1.1
1.4	-2.5	-1.9	-1.5	-1.3
1.6	-2.7	-2.1	-1.7	-1.4
1.8	-2.9	-2.2	-1.8	-1.5
2	-3.1	-2.4	-2.0	-1.7

Recent studies have derived mathematical models that describe the relationship between blood lead metrics and IQ loss. Lanphear et al. (2005), evaluated the statistical relationships between lifetime, peak, and concurrent blood lead levels and IQ test results in seven study cohorts from the U.S. and abroad. When they evaluated "peak" blood lead levels (the highest blood lead measured for each child), they found the following relationship to IQ

*IQ = 99.3 – 2.85 * ln (Concurrent Blood Lead)*

To calculate the difference in predicted IQ between a child with elevated drinking water exposure and a child with "background" exposures, the following simplified form of the equation can be used.

*IQ difference = -2.85 * ln [Blood Lead (exposed) / Blood Lead (background)]*

Because the Lanphear et al. model is nonlinear, estimated IQ losses are dependent on the "background" blood levels against which the increments are measured.

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